Performance of Statistical Comparison Models of Solar Energy on Horizontal and Inclined Surface

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Abstract

Solar radiation data are essential in the design of solar energy conversion devices. In this regard, empirical models were selected to estimate the solar radiation on horizontal and inclined surfaces. We used in this article eleven years of solar radiation over Cairo, Egypt from 1995-2005, and used the statistical parameters ((MBE), (RMSE), MPE, R^2), and t-Test statics, in order to differentiate among these models and choose the best model. The Olmo et al. model was applied to the database corresponding to the horizontal solar irradiation to determine values for a south facing surface, and Olmo et al. model is recommended to estimate the global solar radiation on an inclined surface in this study, due to its accuracy, input requirements and simplicity. The RMSE results indicate that the anisotropic models (Hay, Klucher and Perez) show similar performance on an overall basis, but isotropic model and Tamps and Coulson exhibit much larger error. Generally, the observation of the Perez's and Klucher models describes that the irradiance on inclined plane is more accurate than that in other models.

Keywords

Solar Radiation; Modeling; Isotropic Models; Anisotropic Models; Inclined Surface

Introduction

In the 21st century, engineers and architects are relying increasingly on building energy simulation codes to design more energy-efficient buildings. One of the common traits found in new commercial buildings across Europe and the United States is construction with large glazed facades. Accurate modeling of the impact of solar gains through glazing is imperative especially when simulating the thermal behavior of these buildings. Empirical validations of solar gain models are therefore an important and necessary endeavor to provide confidence for developers and modelers whose respective algorithms simulate reality. The global solar energy incident on a horizontal surface may have direct beam and diffuse solar energy. Diffuse solar energy is usually measured by pyranometers, solarimeters, or actinography while direct beam solar radiation is measured by a pyrheliometer. These measuring devices are usually installed at selected sites in specific region and it is not feasible to install at many sites due to high cost of these devices. In addition, these measuring devices have tolerance and accuracy and consequently wrong/missing records may be found in the data set. The measured solar energy values can be used for developing solar energy models which describes the mathematical relations between the solar energy and the meteorological variables such as ambient temperature, humidity and sunshine ratio. These models can be later used to predict the direct and diffuse solar energy using historical metrological data at sites where there is no solar energy measuring device installed. Solar energy of daylight utilization for any site is dependent upon the quality of the available flux. Obviously, the flux impinging upon any arbitrary surface undergoes monthly as well as diurnal variations. The measurements of energy received from the sun, on horizontal as well as sloped surface, is an expensive affair. As such, few locations in the world have reliable, long-term measured irradiation data sets. Daylight records are even scarcer. Most radiation data are given as the energy received from a horizontal surface. Since only very few applications use this configuration, there is a genuine need for insolation estimation to be carried out for sloped surface on any given aspect, and the accuracy

of these models varies from 40-50% for abbreviated techniques to limits set out by the accuracy of the measuring equipment for modern sophisticated models [Loutzenhiser et al., 2007, Khatib et al., 2012].

The total solar radiation on a horizontal surface is called global irradiance and is the sum of incident diffuse radiation plus the direct normal irradiance projected onto the horizontal surface. If the surface is tilted with respect to the horizontal, the total irradiance is the incident diffuse radiation plus the direct normal irradiance projected onto the tilted surface plus ground reflected irradiance that is incident on the tilted surface [Benghanem, 2011].

The solar radiation that reaches the outer atmosphere is subjected to absorption, reflection and transmission processes through the atmosphere before reaching the earth's surface. Solar radiation data are a fundamental input for solar energy application such as photovoltaic, solar –thermal system and passive solar design. The data should be reliable and readily available for design, optimization and performance evaluation of solar technologies at any particular site and solar radiation is extremely important for the optimal design of solar energy conversion devices [Gueymard, 2000, El-Sebaii, and Trabea, 2005, Ibrahim et al., 2011].

Over the years, several empirical models have been used to estimate solar radiation; utilizing available geographical, climatological and meteorological parameters such as air temperature, relative humidity, sunshine duration, latitude, longitude, precipitation, wind speed, cloudiness were used. Among these, the most commonly used parameter for estimating global solar radiation is sunshine hours. In this respect, the modified version of Angstrom equation, among various correlations, has been widely used to estimate the global solar irradiation on horizontal surface [Muzathik et al., 2011, Kambezidis and Psiloglou, 2008, , Bakirci 2009, Bahel, et al., 1986, Fletcher,.2007, Rehman, 1998, Alnaser, 1993, Trabea and Shaltout, 2000, Sabziparavar, 2007, Kamali et al., 2006, Muneer, Saluja, 1985, Diez et al., 2005, Notton et al., 2006, Martinez et al., 2009, and Perez, 1990].

In most of the solar energy applications, inclined surfaces at different angels are widely employed. The global irradiance on a horizontal surface has been measured in many meteorological stations around the world, but there are only a few stations that measure the solar component on inclined surfaces. There are a number of models available to estimate global irradiation on inclined surface from corresponding horizontal data. This requires, in general, the availability of detailed information on the magnitude of diffuse and direct horizontal irradiance. A number of diffuse fraction models are available as documented in [Liu and Jordan, 1961, Gueymard, 1987, Perez et al., 1990a, Klucher, 1979, Hay, 1979, Li et al., 2002, Khalil, 2010]. These models are usually expressed in terms of polynomial functions relating the diffuse fraction to the clearness index. An inclined surface global irradiation model developed by Olmo et al. [Olmo et al., 1999] requires only the horizontal surface global irradiation, with incidence and solar zenith angles as input parameters.

The global solar energy incident on a horizontal surface may have direct beam and diffuse solar energy. Diffuse solar energy is usually measured by pyranometers, solarimeters, or actinography while direct beam solar radiation is measured by a pyrheliometer. These measuring devices are usually installed at selected sites in specific region and it is not feasible to install at many sites due to high cost of these devices. In addition, these measuring devices have tolerance and accuracy and consequently wrong/missing records may be found in the data set. The measured solar energy values can be used for developing solar energy models which describes the mathematical relations between the solar energy and the meteorological variables such as ambient temperature, humidity and sunshine ratio. These models can be later used to predict the direct and diffuse solar energy using historical metrological data at sites where there is no solar energy measuring device installed. Many solar energy models have been presented in the literature using mathematical linear and nonlinear functions, artificial neural network and fuzzy logic. An important aspect in modeling solar energy is the accuracy of the developed model which is evaluated using statistical errors such as the mean absolute percentage error (MAPE), mean bias error (MBE) and root mean square error (RMSE). The MAPE is an indicator of accuracy in which it expresses the difference between predicted values to the real value. The calculated MAPE is summed for every fitted or forecasted point in time and divided again by the number of fitted points; n. MBE is an indicator for the average deviation of the predicted values from the measured data. A positive MBE value indicates the amount of overestimation in the predicted global solar energy and vice versa. On the other hand, RMSE provides information on the short-term performance of the model and is a measure of the variation of the

predicted values around the measured data. RMSE also shows the efficiency of the developed model in predicting future individual values. A large positive RMSE implies a big deviation in the predicted value from the measured value [Janjai et al., 1996, Chineke T, 2008, Yohanna, 2011, Khatib et al., 2011, Trabea, 2000, El-Sebaii et al., 2010, Li et al., 2011, Alawi et al., 1998, Mihalakakou et al., 2000, Dorvio et al., 2002, Sozen et al., 2004, Fadare, 2009, Lam et al., 2008, Mellit et al., 2008, Reddy, 2003, Benghanem, 2010, Khatib et al., 2011, Hontoria et al., 2005, Zarzalejo et al., 2005, Sen, 1998].

The aim of this paper is to study performance of statistical comparison models of solar energy on horizontal and inclined surface in the selected site, by using empirical models selected to estimate the solar radiation on horizontal and inclined surfaces. The Olmo et al. model was applied to the database corresponding to the horizontal solar irradiation to determine values for a south facing surface.

Database and Climate

In the present work, the global, direct and diffuse solar radiation incident on a horizontal surface at Cairo, Egypt (lat. 30^0 05′ N & Long. 31^0 15′ E), during the period time from January 1995 to December 2005 are used. The radiation data of the corresponding periods are obtained from the Egyptian Meteorological Authority. The used data sets consist of mean hourly and daily values of global and diffuse solar irradiations on a horizontal plane. Global solar radiation was measured using Eppley high-precision pyranometer responsive to 300–3000 nm, while another precision pyranometers equipped with a special shading device, SBS model, was used to measure diffuse irradiation. The shadow band stand is constructed by anodized aluminum, weighs approximately 24 lb and uses a 300 band of approximately 2500 diameter to shade the pyranometer. Because the shadow band screens the sensor from a portion of the incident diffuse radiation coming from the sky, a correction was made to the measurements following Batlles et al. [Elminier, 2007, Batlles et al., 1995]. Global solar radiation data were recorded by the Eppley Precision Spectral Pyranometer (PSP) at all stations. The accuracy of these pyranometers corresponded to the first class according to the World Meteorological Organization classification [WMO, 1990]. These instruments are calibrated each year against a reference instrument traceable to the World Radiometric Reference (WRR) maintained at Davos, Switzerland [WRC, 1985, WRC, 1995]. According to the calibration certificate of the manufacturers, sensitivity is approximately 9 μV/W m^{-2}, temperature dependence is ±1% over ambient temperature range -20 to + 49 ^{0}C, linearity is ±0.5% from 2800 W m^{-2}, and cosine is ±1% from normalization 0 – 70^0 zenith angle and ±3% for 70–80^0 zenith angle. The absolute accuracy of calibration is ±3–4%.

There are few peculiarities in the climate of Egypt that may affect characteristics of the sough relation, which will be outlined here. Cloud characteristics and air temperature change from one season to another as follows: winter is the season of cloud types, normally opaque to the direct beam and minimum temperature, in addition to low turbidity of the atmosphere. Spring is characterized by the passage of small and shallow thermal depressions, inducing what is called Khamasin weather. Vertical visibility is deteriorated progressively with increasing dust content in the lower layers. After the passage of these depressions, clouds form and horizontal visibility are reduced much in the atmosphere. In summer, high temperature, high transparency and semi-transparent clouds prevail, despite their existence, the sky is 'dirty' most of the time, due to deep layer of fine dust particles associated with continental tropical air. The dust content falls markedly when Mediterranean air arrives, associated with fine weather cumulus. In autumn, the atmosphere is fairly transparent on average. Morning mists and low clouds dissipate after sunrise [Metwally, 2004].

Solar Radiation Basic

Computing the Semi-hourly Total Extraterrestrial Solar Radiation G_{oh}

Solar radiation incident outside the earth's atmosphere is called extraterrestrial solar radiation. On average the extraterrestrial irradiance is 1367 W/m^2 (solar constant). The extraterrestrial radiation G_{oh} is given as follows [Bird and Riordan, 1986]:

$$G_{oh} = \frac{24}{\pi} I_{SC} E_0 [\cos\phi \cos\delta \sin\omega + \frac{\pi\omega}{180} \sin\phi \sin\delta] \tag{1}$$

Where E_o is the correction factor of the Earth's orbit and ω is the sunrise/sunset hour angle given by:

$$E_0 = 1 + 0.033\cos(\frac{2\pi dn}{365}) \tag{2}$$

$$\omega = \cos^{-1}(-\tan\phi \tan\delta) \tag{3}$$

And ϕ is latitude and the solar declination angle of the sun (δ) is the angle between a plane perpendicular to a line between the earth and the sun and the earth's axis, which has been given in degrees according to Spencer [Spencer, 1975] as:

$$\delta = (0.006918 - 0.399912\cos\Gamma + 0.070257\sin\Gamma - 0.006758\cos 2\Gamma + 0.000907\sin 2\Gamma - 0.002697\cos 3\Gamma + 0.00148\sin 3\Gamma)\frac{180}{\pi} \tag{4}$$

Where Γ is the day angle in radiance, it is represented by:

$$\Gamma = \frac{2\pi(d_n - 1)}{365} \tag{5}$$

Where d_n is day of the year.

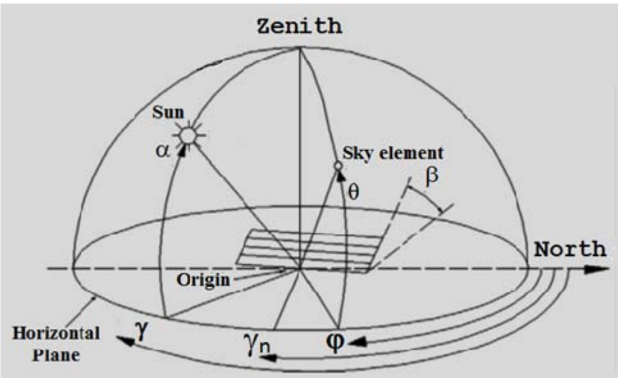

FIG.1 ZENITH, AZIMUTHAL AND HOUR ANGLES

Zenith Azimuthal and Hour Angles

To describe the sun's path across the sky, one needs to know the angle of the sun relative to a line perpendicular to the earth's surface. This is called the zenith angle (θ) and the sun's position relative to the north–south axis, the azimuthal angle (α). The hour angle (ω) is easier to use than the azimuthal angle because the hour angle is measured in the plane of the ''apparent'' orbit of the sun as it moves across the sky (FIG.1) [Benghanem, 2011]. With the above information, one can calculate the cosine of the zenith angle as follow:

$$\cos(Z) = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \tag{6}$$

Modeling of Solar Energy

The commonly used solar energy models developed in the past are based on linear and nonlinear models [Kreider et al., 1991]. These models give a correlation between solar energy on a horizontal surface and some meteorological variables such as; shine hour's s, ambient temperature T, cloud cover c_w, relative humidity R_h, and maximum T_{max}. and T_{min}. ambient temperatures. The linear models use simple linear function while the nonlinear models are polynomial function of the third or fourth degree.

Global Solar Energy Models on Horizontal Surface

Linear and nonlinear models can be used to calculate the global solar energy in terms of sun shine hours. A commonly used linear model for this purpose which defines the global solar energy in terms of the extraterrestrial solar energy is given [Khatib et al., 2012 and, Duffie and Beckman, 1991] as follows:

$$G/G_0 = a + b\tfrac{S}{S_0} \tag{7}$$

$$G/G_0 = a + b\tfrac{S}{S_0} + c(\frac{S}{S_0})^2 \tag{8}$$

$$G/G_0 = a + b\tfrac{S}{S_0} + cT \tag{9}$$

$$G/G_0 = a + b\tfrac{S}{S_0} + cR_h \tag{10}$$

$$G/G_0 = a + bT + cR_h \tag{11}$$

$$G/G_0 = a + b(T_{max} - T_{min}) + cc_\omega \tag{12}$$

$$G/G_0 = a + b(T_{max} - T_{min})^{0.5} + cc_\omega \tag{13}$$

$$G/G_0 = a + b\tfrac{S}{S_0} + cc_\omega \tag{14}$$

$$G/G_0 = a + b(\frac{S}{S_0})^c \tag{15}$$

Where a, b and c are empirical constant and s_o is the maximum possible monthly average daily sunshine duration or the day length.

Computing Beam and Diffuse Radiation on Horizontal Surface

The empirical correlations for calculating the monthly average daily diffuse radiation incident on a horizontal surface, the diffuse fraction (G_d/G) and diffuse transmittance (G_d/G_o) were correlated to first, second and third order correlations of the clearness index (K_t) and the relative number of sunshine hours (S/S_o) [El-Sebaii A et al., 2010]. It is found that the second and third order correlations do not improve the accuracy of estimation of (G_d). Therefore, the following correlations have been obtained for Cairo:

$$G_d/G = 4.215 - 5.447K_t \quad R^2 = 0.968 \tag{16}$$

$$G_d/G = 6.884 - 7.312\frac{S}{S_0} \quad R^2 = 0.934 \tag{17}$$

$$G_d/G = 4.714 - 4.768\frac{S}{S_0} \quad R^2 = 0.916 \tag{18}$$

$$G_d/G = 3.855 - 6.183K_t \quad R^2 = 0.974 \tag{19}$$

Furthermore, (G_d/G) and (G_d/G_o) were correlated to first and second order correlations of the (K_t) and (S/S_o) combination. Also, it has been found that the second order correlations between (G_d/G) or (G_d/G_o) and (K_t) and (S/S_o) combination do not improve the accuracy of estimation of (Gd). The following correlations were found to fit the measured data of (Gd):

$$G_d/G = 5.718 - 5.421K_t + 0.118\frac{S}{S_0}, \quad R^2 = 0.974 \tag{20}$$

$$G_d/G_0 = 4.114 - 3.665K_t - 0.243\frac{S}{S_0}, \quad R^2 = 0.983 \tag{21}$$

Equations from (16) to (21) were used to calculate (Gd) and the obtained results were compared with the measured values of (G_d). The accuracy of estimating (H_d) was checked by calculating the MBE, RMSE, MPE, R^2 and the t-Test.

A simple, physically based method proposed by [Miguel et al., 2001 and Ali et al., 2008] was used for estimating hourly diffuse and direct components from hourly global irradiance. For three different ranges of atmospheric transmissivity ($K_T=G_h/G_{oh}$), the resulting correlations are given by the following expression:

$$\frac{D_h}{G_h} = \begin{cases} 0.995 - 0.081K_t & K_t < 0.21 \\ 0.724 + 2.738K_t^2 + 4.967K_t^2 & 0.21 \le K_t \le 0.76 \\ 0.0180 & K_t > 0.76 \end{cases} \tag{22}$$

Then, we can be calculated the value of the hourly direct solar radiation as follows:

$$B_h = G_h - D_h \tag{23}$$

Global Solar Energy Models on Inclined Surface

The solar collector orientation is extremely important in solar energy systems. Collectors that track the sun by remaining perpendicular to the sun's rays, intercept more solar radiation than the stationary collectors. However, the tracking system is costly. Stationary solar conversion systems are tilted toward the sun in order to maximize the amount of solar radiation incident on the collector or cell surface. Thus, knowledge of the solar global radiation incident on such a tilted surface is a prerequisite for the design of cost effective systems. The amount of elevation from the horizontal, the tilt angle, should be equal to the latitude angle of the location of the collector. This orientation is often selected for flat-plate collector installations, since it averages the installation peaks over the year. The surface axis tilted from the horizon by the latitude angle toward the south, is called an equatorial mounting. This is the ideal way of setting up the collectors. It is also the easiest and cheapest one. In this study, the solar radiation was measured on the inclined surface at inclinations equal to the latitude angle [Muzathik et al., 2011].

In most of the solar energy applications, inclined surfaces at different angles are widely employed. The global irradiation on a horizontal surface has been measured in many meteorological stations around the world, but there are only a few stations that measure the solar component on inclined surfaces. There are a number of models available to estimate global irradiation on an inclined surface from the radiation on a horizontal surface, but these models require knowledge of the global irradiation, direct or diffused irradiation or reflected irradiation on a horizontal surface. An inclined surface global irradiation model developed by Olmo et al. [Muzathik et al., 2011 and Olmo et al., 1999] requires only the horizontal surface global irradiation, with incidence and solar zenith angles as input parameters.

The Olmo et al. [Olmo et al., 1999] model was developed to estimate the global radiation on inclined surfaces using the data collected from horizontal surfaces. This model depends on the clearness index and avoids the direct and diffused solar radiation components. In the case of no ground reflections, the Olmo et al. model estimates the global irradiance (G_β) on an inclined surface from the corresponding global radiation (G) on a horizontal surface by the following equation:

$$G_\beta = G\psi_0 \tag{24}$$

Where (β), is the surface inclination angle and (Ψ_o) is a function that converts the horizontal solar global radiation to that incident on a tilted surface and is given as:

$$\psi_0 = \exp[-K_t(\theta^2 - \theta_z^{\,2})] \tag{25}$$

Where θ and θ_z (in radians) are the incidence and solar zenith angles, respectively, and K_t is the hourly clearness index.

Further, Olmo et al. [Olmo et al., 1999] proposed a multiplying factor (F_c) to take into account anisotropic reflections and it is given as:

$$F_c = 1 + \rho \sin^2(\frac{\theta}{2}) \quad (26)$$

Where ρ is the albedo of the underlying surface, this is the most commonly used expression for the radiation reflected from the ground. In this work a constant value for the albedo is used equal to 0.2.

The Olmo et al. model for determining the global solar radiation on an inclined surface from that on a horizontal surface is then:

$$G_\beta = G\psi_0 F_c \quad (27)$$

The hourly total solar irradiance incident on a tilted surface (G_{Th}) can be divided into three components; the beam component from direct irradiation of the tilted surface (B_{Td}) and the reflected ground (R_{Th}) and sky-diffuse (D_{Th}) components:

$$G_{Th} = B_{Th} + D_{Th} + R_{Th} \quad (28)$$

The amount of direct radiation on a surface tilted (S) degrees from the horizontal and rotated α_T degrees from the north–south axis can be calculated by multiplying the direct horizontal irradiation by the ratio of cosθ/cos(Z), where θ is solar incidence angle on a tilted plane and Z is solar zenith angle. Also, the measuring station was located on a roof-top with very low reflectance, and the reflected component was very much lower than the direct and the diffuse components so an isotropic model can be used to compute the reflected component on the tilted surface. So, Equation (28) can be written again as follows:

$$G_{Th} = \frac{B_h \cos\theta}{\cos Z} + R_d D_h + G_h \rho \frac{1 - \cos S}{2} \quad (29)$$

Where B_h, D_h and G_h are hourly direct, diffuse and total solar radiation on a horizontal surface, either measured directly or estimated from each other, R_d is the ratio of the hourly diffuse irradiation incident on a tilted surface to that on a horizontal surface, ρ is ground reflectivity equal to 0.2 is here assumed because of the lack of a specific measurement, Z is defined from equation (6) and ϑ is calculated by formulae [Ali M. N. et al., 2008]:

$$\cos(Z) = \sin S \sin Z \cos(\alpha S - \alpha T) + \cos S \cos Z \quad (30)$$

Several published meteorological data giving the total solar radiation on horizontal surfaces, correlation procedures are required to obtain insolation values on tilted surfaces from horizontal radiation. Monthly average daily total radiation on a tilted surface (G_T) is normally estimated by individually considering the direct beam (G_B), diffuse (G_D) and reflected components (G_R) of the radiation on a tilted surface. Thus for a surface tilted at a slope angle from the horizontal, the incident total radiation is given by the relation:

$$G_T = G_B + G_D + G_R \quad (31)$$

Several models have been proposed by many numerous [Benghanem, 2011, Kamali et al., 2006, Muneer, Saluja, 1985, Diez et al., 2005, Notton et al., 2006, Martinez et al., 2009, and Perez, 1990, Hay, 1979 and Klucher, 1979] to calculate global radiation on tilted surfaces from the available data on a horizontal surface. The only difference among the models appears in the assessment of sky-diffuse component. Based on the made assumptions the estimation models can be classified into isotropic [Liu and Jordan, 1962] and anisotropic [Hay, 1979 and Klucher, 1979] ones. The daily beam radiation received from an inclined surface can be expressed as:

$$G_B = \frac{G_g - G_d}{R_b} \quad (32)$$

Where G_g and G_d are the monthly mean daily global and diffuse radiation on a horizontal surface, and R_b is the ratio of the average daily beam radiation on a tilted surface to that on a horizontal surface. The daily ground reflected radiation can be written as:

$$G_R = G_g \rho \frac{(1 - \cos\beta)}{2} \quad (33)$$

Where β is the tilt angle of the solar panel, Liu and Jordan [Benghanem, 2011 and Liu and Jordan, 1962] have suggested that R_b can be estimated by assuming that it has the value which would be obtained if there were no atmosphere. For surfaces in the northern hemisphere, sloped towards the equator, the equation for R_b is given as [Liu and Jordan, 1962].

$$R_b = \frac{\cos(\varphi - \beta)\cos\delta \sin\omega_{ss} - \omega_{ss}\sin(\varphi - \beta)\sin\delta}{\cos\varphi \cos\delta \sin\omega_{ss} + \omega_{ss}\sin\varphi \sin\delta} \quad (34)$$

Where ω_{ss} is the sunset hour angle for tilted surface for the mean day of the month, given by the equation (3). For surfaces in the southern hemisphere, sloped towards the equator, the equation for R_b is given as follow:

$$R_b = \frac{\cos(\varphi + \beta)\cos\delta \sin\omega_{ss} + \omega_{ss}\sin(\varphi + \beta)\sin\delta}{\cos\varphi \cos\delta \sin\omega_{ss} + \omega_{ss}\sin\varphi \sin\delta} \quad (35)$$

And then, the total solar radiation on a tilted surface can be expressed as follow:

$$G_T = (G_g - G_d)R_b + G_g \rho \frac{1-\cos\beta}{2} + G_d R_d \qquad (36)$$

As no information is available on ground albedo, ρ values are assumed to be 0.2, according to equation (36), we need the direct and diffuse components of global radiation for estimation global solar radiation on tilted surfaces [Benghanem, 2011].

Diffuse Solar Energy Models on Inclined Surface

The models used to estimate the ratio of diffuse solar radiation on a tilted surface to that of a horizontal are classified as isotropic and anisotropic models. The isotropic models assume that the intensity of diffuse sky radiation is uniform over the sky dome. Hence, the diffuse radiation incident on a tilted surface depends on the fraction of the sky dome seen by it. The anisotropic models assume the anisotropy of the diffuse sky radiation in the circumsolar region (sky near the solar disk) plus and isotropically distributed diffuse component from the rest of the sky dome. The sky-diffuse solar radiation can be expressed as:

$$R_d = R_d G_d \qquad (37)$$

Where R_d is the ratio of the average daily diffuse solar radiation on a tilted surface, to that on a horizontal surface, the diffuse solar radiation models chosen in the present study were as follows [Benghanem, 2011 and Kamali et al., 2006]:

The isotropic sky model [Loutzenhiser et al., 2007, Hottel, 1942, Liu and Jordan 1960 and Duffie J A et al., 1991] is the simplest model that assume all diffuse solar radiation is uniformly distributed over the sky dome, i.e., it is independent on the azimuth and zenith angels. It approximates the completely overcast sky condition. The formula for the hourly sky diffuse solar radiation incident on an inclined plane is given by product of the hourly diffuse solar radiation incident on a horizontal surface and the configuration factor from the surface to the sky, (1 + cos β)/2. For surface tilted by an angle β from the horizontal plane, the total solar irradiance can be written as follow:

$$G_{d,T} = G_{d,H} \frac{(1-\cos\beta)}{2} \qquad (38)$$

The isotropic model is given by Badescu model (Ba) [Badescu, 2002] as follow:

$$R_d = \frac{3+\cos 3\beta}{4} \qquad (39)$$

Tian et al. model (Ti) [Tian et al., 2001] is given by the relation:

$$R_d = 1 - \frac{\beta}{180} \qquad (40)$$

Koronakis model (Kr) [Koronakis, 1986] is given as follow:

$$R_d = \frac{1}{3(2+\cos\beta)} \qquad (41)$$

Liu and Jordan (LJ) [Liu and Jordan, 1962] are given as follow:

$$R_d = \frac{(1+\cos\beta)}{2} \qquad (42)$$

In addition to isotropic diffuse and circumsolar, the Reindl Model also accounts for horizon brightening [Reindl et al., 1990a and Reindl et al., 1990b] and employs the same definition of the anisotropic model.

Reindl et al. model (Re) [Reindl et al., 1990b] is given by the relation:

$$R_d = \frac{G_b}{G_0} R_b + (1 - \frac{G_b}{G_0}) \frac{(1+\cos\beta)}{2} (1 + \sqrt{\frac{G_0}{G_g}} \sin^3 \frac{\beta}{2}) \qquad (43)$$

Skartveit and Olseth model (SO) [Skartveit et al., 1986] is given as follow:

$$R_d = \frac{G_b}{G_0} R_b + \Omega \cos\beta + (1 - \frac{G_b}{G_0} - \Omega) \frac{(1+\cos\beta)}{2} \qquad (44)$$

Where $\Omega = \left\{ Max[0, (0.3 - 2\frac{G_b}{G_0})] \right.$ (45)

Steven and Unswoth model (SU) [Steven et al., 1980] is given by as follow:

$$R_d = 0.51 R_b + \frac{(1+\cos\beta)}{2} - \frac{1.74}{1.26\pi} (\sin\beta - \beta \frac{\pi}{180}) \cos\beta - \pi \sin^2 \frac{\beta}{2} \qquad (46)$$

Hay model (Ha) [Hay, 1979] is given by the relation:

$$R_d = \frac{G_b}{G_0} R_b + (1 - \frac{G_b}{G_0}) \frac{(1+\cos\beta)}{2} \qquad (47)$$

Klucher model, 1979 (Kl) [Klucher, 1979], this model is based on a study of clear sky conditions by Temps and Coulson, 1977 [Temps, 1977]; whose model was modified by Klucher, who incorporated conditions of cloud skies. Klucher's formulation of the hourly sky diffuse solar radiation incident on an inclined surface is:

$$G_{d,T} = G_{d,g} \frac{(1+\cos\beta)}{2} (1 + F_1 \sin^3 \frac{\beta}{2})(1 + F_1 \cos^2 \theta_z \sin^3 \theta_z) \qquad (48)$$

Where F_1 is the modulating function given by: $F_1 = (G_{d,g} / G_g)^2$, when the skies are completely overcast, F = 0, Klucher's model reverts to the isotropic model.

Perez model (Perez et al., 1986; P8, and Perez et al., 1990; P9) [Loutzenhiser, 2007, Perez et al., 1990 and Robaa, 2008] is more computationally intensive and represents a more detailed analysis of the isotropic diffuse, circumsolar and horizon brightening radiation using empirically derived coefficients. The total irradiance on tilted surface is given by the following equation:

$$G_T = G_{h,b}R_b + G_{h,d}[(1-F_1)\frac{(1+\cos\beta)}{2} + F_1\frac{a}{b} + F_2\sin\beta] + G_h\rho\frac{(1-\cos\beta)}{2} \quad (49)$$

Here, F_1 and F_2 are circumsolar and horizon brightness coefficients, respectively, and (a) and (b) are terms that take the incidence angle of the sun on the considered slope into account. The terms (F_1), (F_2), (a) and (b) are computed using the following equations:

$$F_1 = Max[0, f_{11} + f_{12}\Delta + \frac{\pi\theta z}{180} f_{13}] \,\&\, F_2 = f_{21} + f_{22}\Delta + \frac{\pi\theta z}{180} f_{23} \quad (50)$$

$$a = Max(0^0, \cos\theta) \,\&\, b = Max(\cos 85, \cos\theta_z) \quad (51)$$

The coefficients f_{11}, f_{12}, f_{13}, f_{21}, f_{22} and f_{23} were derived based on a statistical analysis of empirical data for specific locations. Two different sets of coefficients were derived for this model [Temps et al., 1977 and Perez et al., 1990].

Comparison Techniques of Modeling

The relative ability of the different models to predict the global radiation on horizontal and tilted surfaces was tested. The performance of the individual models was determined by utilizing statistical methods. There are numerous works in literature which deal with the assessment and comparison of daily solar radiation estimation models. The most popular are the MBE (mean bias error) and the RMSE (root mean square error). In this study, to evaluate the accuracy of the estimated data, from the models described above, the following statistical estimators were used, MBE, RMSE, MPE (mean percentage error) and the correlation coefficient (R^2), to test the linear relationship between predicted and measured values. For higher modeling accuracy, these estimators should be closer to zero, and the correlation coefficient, (R^2), should approach to 1. The NSE (Nash-Sutcliffe equation) was also selected as an evaluation criterion. A model is more efficient when NSE is closer to 1. However, these estimated errors provide reasonable criteria to compare models but fail to objectively indicate whether the estimates from a model are statistically significant. The t-statistic allows models to be compared and at the same time it indicates whether or not a model's estimate is statistically significant at a particular confidence level. So, the t-test was carried out on the models to determine the statistical significance of the predicted values [Muzathik et al., 2011].

Mean Bias Error (MBE)

To evaluate the accuracy of the prediction data from the models described above, this test provides information on the long-term performance of a model. A low MBE value is desired. A negative value gives the average amount of underestimation in the calculated value. So, one drawback of MBE is that overestimation of an individual observation may cancel underestimation in a separate observation. The values of MBE can be obtained as follow:

$$MBE = \frac{1}{n}\sum_1^n (G_{i,calc} - G_{i,meas}) \quad (52)$$

And the equation of mean percentage error MPE% is expressed by|:

$$MBE\% = \frac{1}{n}\sum_1^n \frac{(G_{i,calc} - G_{i,meas})}{G_{i,meas}} * 100\% \quad (53)$$

The subscript i refers to the ith value of the daily solar irradiation; and n is the number of the daily solar irradiation data. The subscripts "calc." and "meas." refer to the calculated and measured daily solar irradiation values, respectively. A percentage error between -10% and +10% is considered acceptable [Glover et al., 1958].

Root Mean Square Error (RMSE)

The value of RMSE is always positive, representing zero in the ideal case. The normalized RMSE gives information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the predicted and measured values. The smaller the value is, the better the model's performance is, and the equation of RMSE as follows [Iqbal, 1983]:

$$RMBE = [\frac{1}{n}\sum_1^n (G_{i,calc} - G_{i,meas})]^{1/2} \quad (54)$$

The t-Test statistic (t)

The tests for mean values, the random variable t with (n-1) degrees of freedom may be written here as follows [Elminir et al., 2006]:

$$t = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}} \quad (55)$$

The smaller values of *t*-statistic are, the better the performance of modeling is.

The Correlation Coefficient (R2)

In statistics literature, it is the proportion of variability in a data set that is accounted for by a statistical model, where the variability is measured quantitatively as the sum of square deviations. Most often it is defined notationally as:

$$R^2 = \frac{\sum_{i=1}^{n}[2(X_i - Y_i)]}{\sum_{i=1}^{n}[2(X_i - Y_i)]} \quad (56)$$

This can also be expressed as:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}[2(X_i - Y_i)]}{\sum_{i=1}^{n}[2(X_i - Y_i)]} \quad (0 \le R^2 \le 1) \quad (57)$$

Herein, *Xi* and *Yi* are the measurements and model estimates, respectively. A high value of R^2 is desirable as this shows a lower unexplained variation. R^2 is a statistic that gives some information about the goodness-of-fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1.0 indicates that the regression line perfectly fits the data, which is never valid in any solar radiation estimation model.

Results and Discussion

The monthly average daily of global solar radiation, beam and diffuse solar radiation on a horizontal surface shows in fig. (2), and from this figure we notice that, in summer months, the beam component is more dominant than diffuse component and in winter months, the beam radiation nearly varies from 68% to 76% of global radiation, while diffuse radiation nearly varies from 27% to 38% of global radiation. Meanwhile, it is clear that the solar irradiance measurements are strongly affected by cloud. Surface measur-ements of the diffuse component of the solar irradiance are particularly sensitive to cloud amount. The clouds are divided into (i) a cloudless day, and (ii) an overcast morning and an afternoon with broken clouds. In many cloud days, the conditions varied throughout the day from overcast in the morning, with cloud gradually breaking up throughout the afternoon to the early evening when the clouds are cleared completely. These results are in a good agreement with other work given by [Ibrahim et al., 2011].

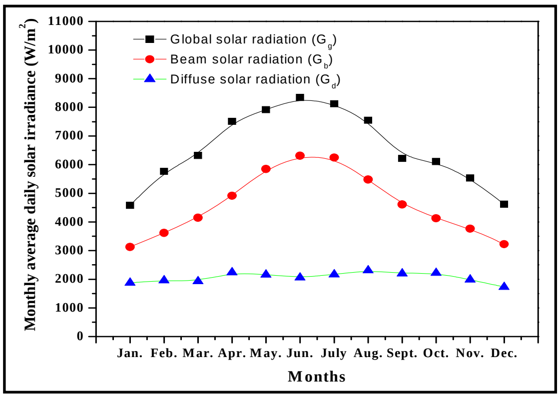

FIG.2 MONTHLY AVERAGE DAILY OF GLOBAL IRRADIATION (G_G), BEAMS (G_B) AND DIFFUSE (G_D) IRRADIATION (W/M^2) ON A HORIZONTAL SURFACE IN SELECTED LOCATION.

Empirical correlations for estimation of global solar radiation on horizontal surface in the form of Equations from (7) to (15) were proposed for Cairo using the meteorological data during the period time (1995-2005). From the analysis of the measured and calculated values of (G), the regression equations between (G/G_o) and meteorological variables along with the values of (MBE), (RMSE), MPE, R^2 and the t-test statics are summarized in Table (1). It is clear that, the values of correlation coefficients (R^2) are higher than 0.94 and the values of the RMSE are found the range 2.19 – 5.73, which indicates fairly good agreement between measured and calculated values of total solar radiation (G). The negative values of the MPE show that, equations (7, 8, 9, 10, and 12) slightly overestimate the values of the total solar radiation (G), but, equations (11, 13, 14 and 15) slightly underestimate of the global solar radiation (G). In all cases, the absolute values of the MPE never reach 1.8%, indicating very good agreement between the monthly average of daily global solar radiation and the other meteorological parameters. Also from table (1), it is seen that, the values of (t-Test) change in model to another model according to models from equations (7-15). Thus the model which gives the smallest values of the t-Test, is considered as the best model for estimating the global solar radiation at selected site with an acceptable error. This means that the models of equations (9) and (10) are good estimate for the global solar radiation in selected location during the period time in the present work.

Comparisons between the measured ($G_{d,m}$) and calculated ($G_{d,c}$) values of the diffuse solar radiation along with the values of mean base error (MBE), root mean square error (RMSE), mean percentage error (MPE), and t-Test statics are summarized in Table (2). It is clear that the low values of the (RMSE) for all models indicate fairly good agreement between measured and calculated values of diffuse solar radiation (G_d). The negative values of (MPE) indicate that the proposed correlations slightly overestimate (G_d). For all models, the absolute values of the (MPE) never reach 1.3%, indicating very good agreement between measured and calculated values of the diffuse solar fraction (G_d/G) or the diffuse solar transmittance (G_d/G_o) and clearness index K_t, relative number of sunshine hours (S/S_o) and the combination of them. The latter results are confirmed for each month. Likewise, from the TABLE 2, the *t*-Test of the model in equation (20) giving the smallest value, is considered as the best model for estimating the diffuse solar radiation at selected site with an acceptable error. These results are in good agreement with pervious work performed for other studies [El-Sebaii et al., 2010].

The linear regression analysis was used to compared between measured and calculated values of the global solar radiation, measured and calculated values of beam solar radiation and measured and calculated values of diffuse solar radiation in the selected site during the period time from 1995 to 2005 are show in figures 3, (a, b and c) respectively.

The Olmo et al. [Muzathik et al., 2011 and Olmo et al., 1999], model was applied to the database corresponding to the horizontal solar global irradiation to determine values for a south facing surface, tilted at latitude angle for all sky conditions. The hourly solar irradiation data have been used in this study and the statistical coefficients have been computed on the basis of the experimental data. The results of the statistical analysis of the relative ability of the Olmo et al. model to determine the solar global irradiation on the inclined surface are presented in table (3). It is evident from TABLE 3 that the mean percentage error (MPE) in the range of (MBE and RMSE) of all months is the nearest among them. Normally, these months are subject to heavy rainfall and less solar radiation. The high values of MPE and RMSE and low value of correlation coefficient for these months can be justified. The model provides a good estimation tool for the other months. In general, considering the statistics as a whole, the global solar radiation data estimated by Olmo et al. model are in good agreement with the measured values.

TABLE 1 EMPIRICAL CORRELATIONS DESCRIBE THE RELATION BETWEEN (G/G_o), (W/M^2) AND METROLOGICAL VARIABLE AT CAIRO, EGYPT DURING THE PERIOD TIME (1995-2005).

Model No.	Regression coefficients			MBE	RMSE	MPE%	R^2	t-Test
	a	b	c					
Equation (7)	0.632	0.311	-	-3.59	3.46	-5.91	0.965	4.89
Equation (8)	0.632	0.311	0.548	-3.44	3.33	-5.83	0.981	4.77
Equation (9)	0.183	0.512	0.654	-2.09	2.19	-2.92	0.987	3.45
Equation (10)	0.154	0.723	0.526	-3.25	2.26	-3.74	0.962	3.94
Equation (11)	0.345	-0.521	0.783	4.58	4.42	5.23	0.977	5.11
Equation (12)	0.426	0.547	0.489	5.74	5.73	-3.86	0.992	6.12
Equation (13)	-0.327	0.473	-0.624	-4.11	3.94	2.74	0.976	7.12
Equation (14)	-0.422	0.411	0.498	-3.94	4.63	6.43	0.953	6.24
Equation (15)	0.591	0.386	0.715	-2.79	3.76	7.65	0.958	5.89

TABLE 2 COMPARISON BETWEEN MEASURED (GD,M) AND CALCULATED (GD,C) VALUES (W/M2) WITH THE METROLOGICAL VARIABLE AT CAIRO, EGYPT DURING THE PERIOD TIME (1995-2005).

Model No.	$G_{d,m}$	$G_{d,c}$	MBE	RMSE	MPE%	t-Test
Equation (16)	1379	1325	-1.23	2.14	-1.59	2.14
Equation (17)	1419	1485	1.12	2.46	2.25	2.56
Equation (18)	1465	1399	0.895	1.95	1.68	1.89
Equation (19)	1398	1346	1.09	2.74	-1.89	1.45
Equation (20)	1321	1369	-1.35	1.88	2.48	1.24
Equation (21)	1375	1327	-1.68	2.13	-2.18	2.35

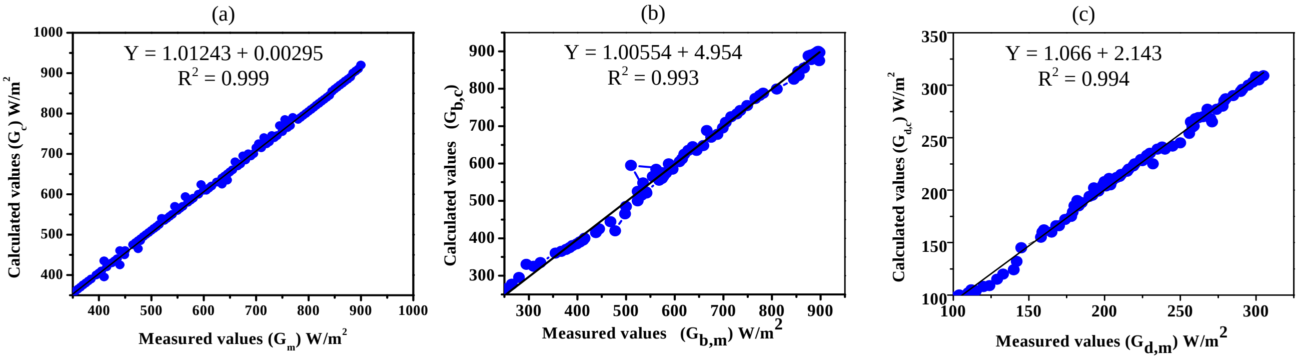

FIG. 3 COMPARISON BETWEEN MEASURED AND CALCULATED VALUES; (A), GLOBAL SOLAR RADIATION, (B), BEAM SOLAR RADIATION AND (C) DIFFUSE SOLAR RADIATION.

TABLE 3 STATISTICAL RESULTS ANALYSIS FOR OLMO ET AL., IN THE PRESENT STUDY

Month	MBE	RMSE	MPE%	R^2	t-Test
January	28.12	41.56	8.98	0.915	5.21
February	22.45	35.25	6.75	0.945	4.65
March	17.85	29.55	5.67	0.987	3.99
April.	19.32	30.21	6.23	0.979	5.34
May	-5.92	27.61	4.56	0.962	3.74
June	8.67	20.32	3.25	0.987	2.97
July	9.42	21.47	3.55	0.975	2.55
August	7.64	23.85	4.12	0.973	3.85
September	8.59	19.54	5.32	0.987	4.21
October	14.58	25.92	6.89	0.971	5.96
November	18.35	32.65	7.24	0.923	5.81
December	31.56	44.85	8.46	0.908	6.25

Therefore, Olmo et al. model is recommended to estimate the global solar radiation on an inclined surface in this study, due to its accuracy, input requirements and simplicity.

Fifth solar irradiance models are considered in this article; and the isotropic model, Hay, Klucher's, Perez and Tamps and Coulson's are anisotropic models. For each model, measured diffuse and horizontal values of global solar radiation were used to calculate the solar radiation on surface tilted at 15^0, 30^0, 45^0, 60^0, 75^0, and 90^0 above the horizon. The results were compared with the solar irradiances monitored and presented in terms of usual statistics: the mean base error (MBE) and the root mean square error (RMSE). In Figure (4), showing the results for south facing surfaces of the mean base error (MBE) for different slope at different models in the present work, it is seen that, the values of MBE varies from -0.52 to -12.25, -0.67 to -9.24, -0.49 to -6.37, -0.45 to -6.32, 1.56 to 9.65 for isotropic, Hay, Klucher, Perez and Tamps respectively. The values of MBE results show that the isotropic, Perez's, Hay's and Klucher's models are substantially under predicted the irradiance incident on an inclined surface, and the Tamps and Coulson model considerably over predicts irradiance incident on an inclined surface on an overall basis.

Figure (5), shows the results for south facing surfaces of the root mean square error (RMSE) for different slope at different models in the present work. From these table, we observed that, the values of root mean square error varied from 3 to 33, 2.1 to 19, 2.4 to 16.3, 1.09 to 12.3, 4.9 to 19.8 for; isotropic, Hay, Klucher, Perez and Tamps respectively. From these values we conclude that, the RMSEs values for all fifth models increases as the slop of the collector increase, but remain in a domain of error for which these relations can be applied with good accuracy. Inspecting the results, it is apparent that the models agree quit well with each other during the summer months. They deviate from each other in the winter months, when the effect of the difference in the diffuse solar radiation parameterization is at its maximum. The RMSE results indicate that the anisotropic models (Hay, Klucher and Perez) show similar performance on an overall basis, but isotropic model and Tamps and Coulson exhibit much larger error. In general we confirm that, the observations of the Perez's and Klucher models describe the irradiance on inclined plane more accurately than that in other models. These results in the present work are good agreement with other work in this field [Elminir et al., 2006].

The diffuse models chosen for study were the isotropic models of Badescu (Ba) [Badescu V., 2002], Tian et al. (Ti) [Tian Y Q et al., 2001], Koronakis (Kr) [Koronakis,1986] and Liu and Jordan (LJ) [Liu and Jordan, 1962], and the anisotropic models of Perez et al. (P9) [Robaa, 2008], Reindl et al. (Re) [Reindl,1990a], Perez et al. (P8) [Perez R., 1987], Skartveit and Olseth (SO) [Skartveit and Olseth, 1980], Steven and Unsworth (SU) [Steven and Unsworth, 1980], Hay (Ha) [Hay, 1979], Klucher (Kl) [Klucher,1979], and Temps and Coulson (TC) [Temps and Coulson, 1977]. For more information about models and mathematical relationships between these models and the comparison of regression (model = a + b x measured) and mean base error (MBE), root mean square error (RMSE), mean percentage error (MPE), correlation coefficient (R^2) and t-Test statics of different hourly models for south – facing and west – facing in this research are referred to tables (4 and 5) respectively.

The evaluation was carried out on a semi-hourly basis. The total solar radiation component on the tilted surface was determined by measured horizontal data using different models and compared with the measured tilted data of the same period in the present work. Tables (4 and 5), report a summary of the statistical results of the models for south facing and west facing surface in the present study respectively. It is seen that from table (4), the absolute relative values of the root mean square error (RMSE), for the south facing surface range from 12.4 to 39.7 for Hay (Ha) model and Stevenand Unsworth (SU) model respectively. These results are good agreement with the values of t-Test statistics for the same models and the correlation coefficient is clear that the higher value also fit for self-models. For west-facing surface show in table (5), the values of root mea square error range from 15.7 to 48.6 for Perez et al. (P9) and Temps and Coulson (TC) models respectively. From tables (4 and 5), we concluded that the models Hay (Ha), Skartveit and Olseth (SO) and Perez et al. (P9) are given to the most accurate predictions for the south-facing surface, and Hay (Ha) and Perez et al. (P9) models performs better on the estimation for the west-facing surface.

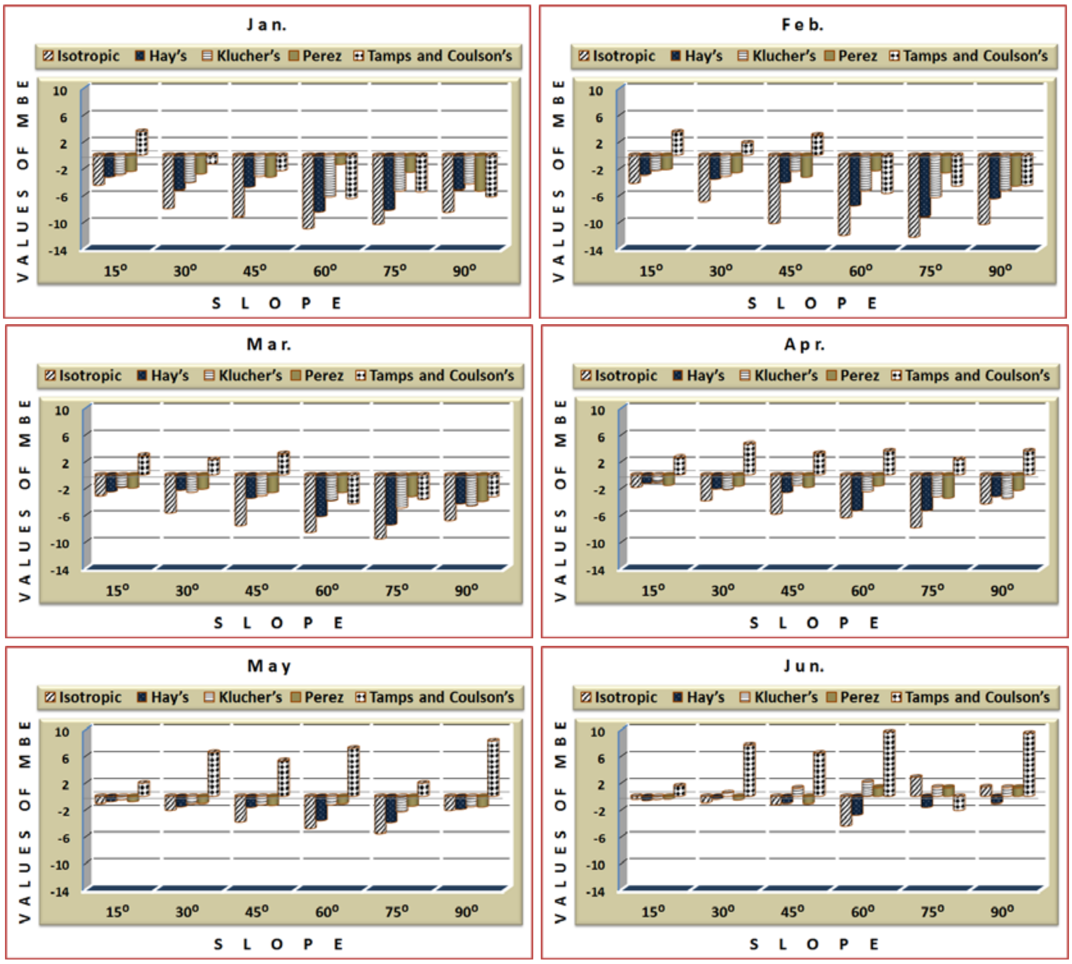

FIG. 4 THE MONTHLY VALUES OF THE MEAN BASE ERROR (MBE %) FOR GLOBAL SOLAR RADIATION RECEIVED ON INCLINED SURFACE

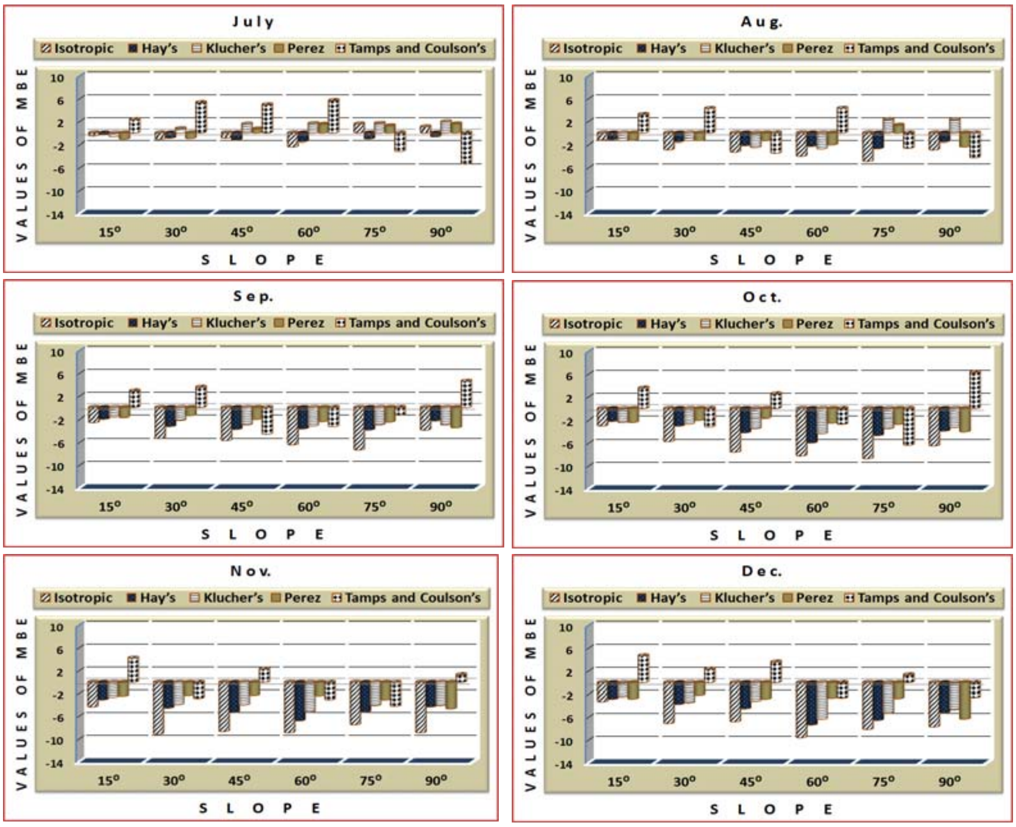

FIG.4 CONT

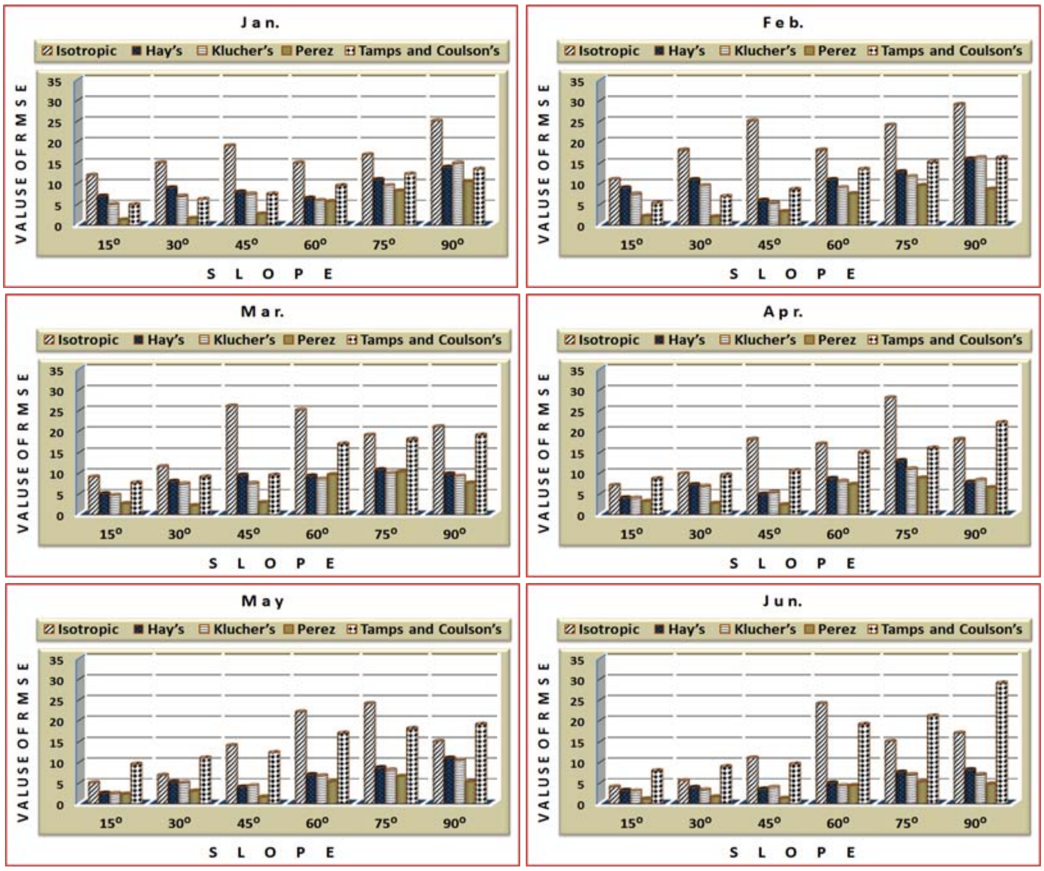

FIG.5 THE MONTHLY VALUES OF THE ROOT MEAN SQUARE ERROR (RMSE %) FOR GLOBAL SOLAR RADIATION RECEIVED ON INCLINED SURFACE

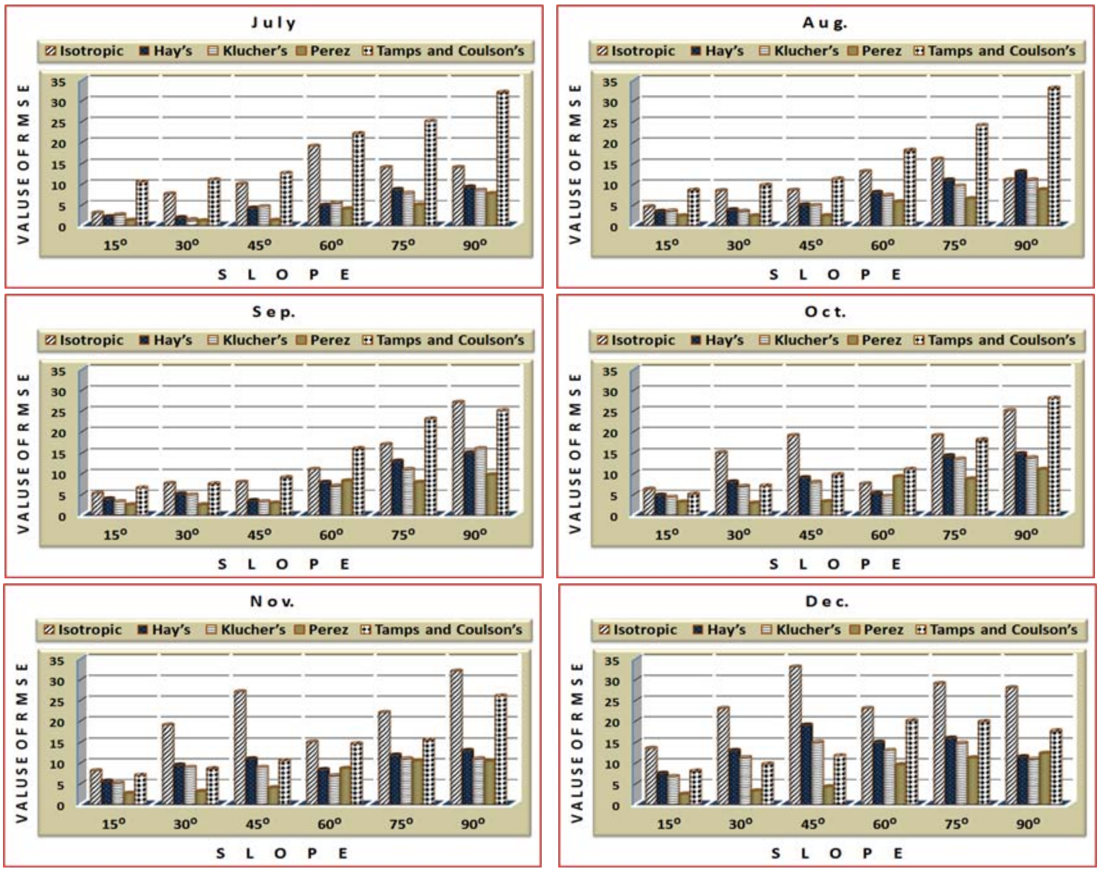

FIG. 5, CONT.

TABLE 4 THE STATISTICAL RESULTS OF THE MODELS FOR THE SOUTH – FACING SURFACE AT CAIRO, EGYPT DURING THE PERIOD TIME FROM 1995 TO 2005

Model	Abbreviation	Year	a	b	MBE	RMSE	MPE	R^2	t-Test
Liu and Jordan	LJ (ISO)	1962	0.123	0.354	-14.4	27.2	-9.5	0.975	8.96
Temps and Coulson	TC (ANI)	1977	0.234	0.624	18.2	31.6	10.3	0.968	9.23
Hay	Ha (ANI)	1979	0.321	0.452	-32.6	12.4	12.8	0.992	5.24
Stevenand Unsworth	SU (ANI)	1980	0.514	0.610	23.4	39.7	13.9	0.952	10.44
Skartveit and Olseth	SO (ANI)	1986	0.612	0.287	-11.2	15.2	-8.3	0.989	6.25
Koronakis	Kr (ISO)	1986	0.124	0.621	-25.5	23.7	11.7	0.974	7.95
Perez et al.	P8 (ANI)	1986	0.247	0.452	15.8	19.9	14.3	0.979	8.21
Reindl et al.	Re (ANI)	1990	0.314	0.587	18.3	14.5	13.7	0.988	5.41
Perez et al.	P9 (ANI)	1990	0.415	0.354	-12.7	16.7	-7.6	0.986	6.34
Tian et al.	Ti (ISO)	2001	0.432	0.412	16.2	22.7	11.3	0.969	8.36
Badescu	Ba (ISO)	2002	0.524	0.341	-21.7	26.7	14.8	0.958	9.11

(ISO, means isotropic and ANI means anisotropic)

TABLE 5 THE STATISTICAL RESULTS OF THE MODELS FOR THE WEST – FACING SURFACE AT CAIRO, EGYPT DURING THE PERIOD TIME FROM 1995 TO 2005

Model	Abbreviation	Year	a	b	MBE	RMSE	MPE	R^2	t-Test
Liu and Jordan	LJ (ISO)	1962	0.355	0.245	-15.7	35.4	-12.8	0.962	9.56
Temps and Coulson	TC (ANI)	1977	0.295	0.465	-19.5	48.6	13.2	0.954	10.45
Hay	Ha (ANI)	1979	0.425	0.511	-39.4	16.7	16.5	0.995	6.64
Stevenand Unsworth	SU (ANI)	1980	0.621	0.324	-20.6	45.5	11.4	0.921	12.54
Skartveit and Olseth	SO (ANI)	1986	0.547	0.309	19.9	18.4	-11.6	0.974	7.75
Koronakis	Kr (ISO)	1986	0.345	0.445	-22.3	33.6	15.4	0.967	9.67
Perez et al.	P8 (ANI)	1986	0.456	0.389	14.6	23.5	17.2	0.987	8.95
Reindl et al.	Re (ANI)	1990	0.452	0.375	-16.9	17.3	15.6	0.994	6.49
Perez et al.	P9 (ANI)	1990	0.329	0.412	-15.4	15.7	11.3	0.997	5.26
Tian et al.	Ti (ISO)	2001	0.324	0.359	-19.6	32.2	13.5	0.972	7.78
Badescu	Ba (ISO)	2002	0.496	0.411	-26.3	36.9	17.4	0.969	11.24

(ISO, means isotropic and ANI means anisotropic)

Conclusion

The monthly average daily of total solar radiation, beam and diffuse solar radiation on a horizontal surface is measured. In summer months, the beam component is more dominant than diffuse component and in winter months, the beam radiation nearly varies from 68% to 76% of global radiation, while diffuse radiation nearly varied from 27% to 38% of global radiation. Also, it is clear that the solar irradiance measurements are strongly affected by cloud.

The values of the (RMSE) for all models indicate fairly good agreement between measured and calculated values of diffuse solar radiation (Gd). The negative values of (MPE) indicate that the proposed correlations slightly overestimate (Gd). For all models, the absolute values of the (MPE) never reach 1.3%, indicating very good agreement between measured and calculated values of the diffuse solar fraction (Gd/G) or the diffuse solar transmittance (Gd/Go) and clearness index Kt, relative number of sunshine hours (S/So) and the combination of them.

The results of the statistical analysis of the relative ability of the Olmo et al. model to determine the solar total irradiation on the inclined surface are presented. Olmo et al. model are in good agreement with the measured values. Therefore, Olmo et al. model is recommended to estimate the total solar radiation on an inclined surface in this study, due to its accuracy, input requirements and simplicity.

Fifth solar irradiance models using in this article; the isotropic model, Hay, Klucher's, Perez and Tamps and Coulson's are anisotropic models with different slope (150, 300, 450, 600, 750, and 900) above the horizon. The values of MBE results show that the isotropic, Perez's, Hay's and Klucher's models are substantially under predicts the irradiance incident on an inclined surface, and the Tamps and Coulson model considerably over predicts irradiance incident on an inclined surface on an overall basis. The RMSE results indicate that the anisotropic models (Hay, Klucher and Perez) show similar performance on an overall basis, but isotropic model and Tamps and Coulson exhibit much larger error. Generally, the observations of the Perez's and Klucher models describe the irradiance on inclined plane more accurately than that in other models. The diffuse models chosen for study were the anisotropic models Hay (Ha), Skartveit and Olseth (SO) and Perez et al. (P9) which were given to the most accurate predictions for the south-facing surface, and Hay (Ha) and Perez et al. (P9) models perform better on estimation for the west-facing surface.

REFERENCES

Alnaser W.E., 1993. New model to estimate the solar global irradiation using astronomical and meteorological parameters, Renewable Energy 3:175-7.

Badescu V., 2002, A new kind of cloudy sky model to compute instantaneous values of diffuse and global irradiance, Theor. Appl. Climatol., 72: 127–36.

Bakirci K., 2009, Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey. Energy, 34:485-501.

Batlles F. J., Olmo F. J., and Alados A., 1995: On shadow band correction methods for diffuse irradiance measurements. Solar Energy 54: 105–14.

Benghanem M., and Mellit A., 2010, Radial basis function network-based prediction of global solar radiation data: application for sizing of a stand-alone photovoltaic system at Al-Madinah, Saudi Arabia. Energy 35: 3751–62.

Benghanem M., 2011, Optimization of tilt angle for solar panel: case study for Madinah, Saudi Arabia, Applied Energy, 88, 1427-1433.

Bird R.E. and Riordan C. J., 1986, Simple solar spectral model for direct and diffuse irradiance on horizontal and tilted planes at the Earth's surface for cloudless atmosphere, J. Climate Appl. Meteorol., 25: 87- 97.

Chineke T. 2008, Equations for estimating global solar radiation in data sparse regions. Renew Energy 33: 827–31.

Diez-M., Miguel A. and Bilbao J., 2005, Measurement and comparison of diffuse solar irradiance models on inclined surfaces in Valladolid (Spain), Energy Convers Manage 46: 2075–92.

Dorvio A., Jervase J. A. and Lawati A., 2002, Solar radiation estimation using artificial neural networks, Applied Energy 74: 307–19.

Duffie J.A. and Beckman W., 1991, Solar engineering of thermal processes, Second ed. John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore.

El-Metwally M., 2004, Simple new method to estimate global solar radiation based on meteorological data in Egypt, Atmospheric Research, 69: 217 – 239.

Elminir K., Gihetas A., El-Hussainy F., Hamid R., Beheary M. and Menoum K., 2006, Optimum solar flat-plate collector slope: Case study for Helwan, Egypt, Energy Conversion and Management, 47, 5 , 624 – 637.

Elminir K., 2007, Experimental and theoretical investigation of diffuse solar radiation: Data and models quality tested for Egyptian sites, Energy 32, 73–82.

El-Sebaii A. and Trabea A., 2005: Estimating global solar radiation on horizontal surfaces over Egypt, Egypt J Solids 28:163–75.

El-Sebaii A., Al-Hazmi F., Ghamdi A. and Yaghmour S. Global, 2010, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. Appl. Energy 87: 568–76.

Fadare D., 2009: Modelling of solar energy potential in Nigeria using an artificial neural network model, Appl. Energy 86: 1410–22.

Fletcher A. L., 2007, Estimating daily solar radiation in New Zealand using air temperatures. New Zealand Journal of Crop Horticultural Science, 35:147-57.

Gueymard G., 2000, Prediction and Performance Assessment of Mean Hourly Global Radiation, Solar Energy, Vol. 68, No. 3, pp. 285-303.

Hay J. E., 1979. Calculation of monthly mean solar radiation for horizontal and inclined surfaces, Solar Energy 23: 301-7.

Hottel, H.C., Woertz, B.B., 1942, Evaluation of flat-plate solar heat collector, Trans., ASME. 64. 91.

Hontoria L., Aguilera J. and Zufiria P., 2005: An application of the multilayer perceptron: solar radiation maps in Spain. Solar Energy 79: 523–30.

Ibrahim A., El-Sebaii A., Ramadan M., and El-Broullesy S., 2011, Estimation of solar irradiance on inclined surfaces facing south in Tanta, Egypt, International Journal of Renewable Energy Research, IJRER, Vol. 1, No.1, pp.18-25.

Iqbal M., 1983, An introduction to solar radiation, New York: Academic Press; 1983.

Janjai S. and Moonin C., 1996, A new model for computing monthly average daily diffuse radiation for Bangkok. Renew. Energy 9: 1283–6.

Kamali G. h., Moradi A. I. and Khalidi A., 2006, Estimating solar radiation on titled surfaces with various orientations: a case study in Karaj (Iran), Theor. Appl. Climatol, 84: 235–41.

Kambezidis H. D., Psiloglou B. E., 2008. The meteorological radiation model: advancements and application. In: Badescu V, editor, models solar radiation at the earth's surface, Springer, Verlag; [Chapter 19].

Khatib T., Mohamed A., Sopian K. and Mahmoud M. 2011, Modeling of solar energy for Malaysia using artificial neural networks, In: The 11th WSEAS/IASME International Conference on Electric Power Systems, High Voltages, and Electric Machines pp. 486–9.

Khatib T., 2011, Mohamed A, Mahmoud M, Sopian K. Modeling of daily solar energy on a horizontal surface for five main sites in Malaysia. Int J Green Energy 8:795–819.

Klucher T. M., 1979. Evaluations of models to predict insolation on tilted surfaces, Solar Energy 23: 111-4.

Koronakis P. S., 1986, On the choice of the angle of tilt for south facing solar collectors in the Athens basin area, Solar Energy 36: 217.

Lam J., Wan K., and Yang L., 2008. Solar radiation modelling using ANNs for different climates in China, Energy Convers Manage 49: 1080–90.

Liu B. and Jordan R., 1962, Daily insolation on surfaces tilted towards the equator, Trans ASHRAE 67.

Liu, B.Y. H. and Jordan R. C., 1960, The interrelationship and characteristic distribution of direct, diffuse, and total solar radiation. Solar Energy, 4 (3), 1–19.

Liu B. Y. H. and Jordan R. C., 1961, Daily insulation on surfaces tilted towards the equator, ASRHAE Journal 3: 53-69.

Li D., Lam J. and Lau C., 2002. A new approach for predicting vertical global solar irradiance, Renewable Energy 25:591-606.

Li H., Ma W., Wang X. and Lian Y., 2011, Estimating monthly average daily diffuse solar radiation with multiple predictors: a case study, Renew Energy 36: 1944–8.

Loutzenhiser P. G., Manz H., Felsmann C., Strachan P.A., Frank T. and Maxwell G.M., 2007, Empirical validation of models to compute solar irradiance on inclined surfaces for building energy simulation, Solar Energy, 81; 254-276.

Martínez M., Zarzalejo L. F., Bosch J. L., Rosiek S., Polo J. and Batlles F.J., 2009, Estimation of global daily irradiation in complex topography zones using digital elevation models and meteosat images: comparison of the results. Energy Convers Manage 50: 2233–8.

Mellit A., Kalogirou S., Shaari S., Salhi H. and Arab A., 2008, Methodology for predicting sequences of mean monthly clearness index and daily solar radiation data in remote areas: application for sizing a stand-alone PV system. Renew Energy 33: 1570–90.

Mihalakakou G., Santamouris M. and Asimakopoulos D. N., 2000: The total solar radiation time series simulation in Athens, using neural networks, Theor. Appl. Climatol., 66: 185–97.

Miguel A., Bilbao J., Aguiar R., Kambezidis H. and Negro E., 2001, Diffuse solar radiation model evaluation in the north Mediterranean belt area, Solar Energy 70:143–53.

Muzathik A.M., Ibrahim M.Z., Samo K.B. and Nik W.B., 2011, Estimation of global solar irradiation on horizontal and inclined surfaces based on the horizontal measurements, Energy, 36, 812-818.

Noorian A. M., Moradi I. and Kamali G. A., 2008, Evaluation of 12 models to estimate hourly diffuse irradiation on inclined surfaces, Renewable Energy, 33, 1406 – 1412.

Notton G., Poggi P., and Cristofari C., 2006, Predicting hourly solar irradiations on inclined surfaces based on the horizontal measurements: performances of the association of well-known mathematical models, Energy Convers Manage 47; 1816–29.

Olmo F. J., Vida J., Foyo I., Castro-Diez Y. and Alabos-Arboledas L., 1999, Prediction of global irradiance on inclined surfaces from horizontal global irradiance, Energy 1999; 24: 689-704.

Perez R., Seals R., Ineichen P., Stewart R. and Menicucci D., 1987, A new simplified version of the Perez diffuse irradiance model for tilted surfaces, Solar Energy, 39 (3), 221–232.

Perez R., Ineichen P., Seals R., Michalsky J. and Stewart R., 1990. Modeling daylight availability and irradiance components from direct and global irradiance, Solar Energy, 44 (5), 271–289.

Perez R., Ineichen P., Seals R., Michalsky J. and Stewart R., 1990a, Modeling daylight availability and irradiance components from direct and global irradiance, Solar Energy 44: 271-89.

Reddy K. and Ranjan M. 2003, Solar resource estimation using artificial neural networks and comparison with other correlation models, Energy Convers Manage 44: 2519–30.

Reindl D.T., Beckmann W. A., and Duffie J. A., 1990b. Evaluation of hourly tilted surface radiation models, Solar Energy 45 (1), 9–17.

Reindl, D.T., Beckmann W. A., Duffie and J. A., 1990a: Diffuse fraction correlations, Solar Energy 45 (1), 1–7.

Robaa S. M., 2008, Evaluation of sunshine duration from cloud data in Egypt, Energy 33: 785 – 95.

Sabziparavar A., and Shetaee H., 2007, Estimation of global solar radiation in arid and semi-arid climates of east and west Iran, Energy, 32: 649–55.

Skartveit A. and Olseth J. A., 1986, Modelling slope irradiance at high latitudes. Solar Energy, 36 (4): 333–44.

Samy A. Khalil, 2007. Empirical correlations for diffuse solar radiation from global solar radiation and sunshine duration over Egypt, Al-Azhar Bull., Sci., Vol. 14 No. 2 (Dec.): 203-210.

Samy A. Khalil, 2010. Evaluation of Models for Prediction of Monthly Mean Hourly Sky-Diffuse Solar Radiation on Tilted Surface, Cairo, Egypt, International Journal of Pure and Applied Physics, Volume 6, Number 3 pp. 303–310.

Sozen A., Arcakly´ E., Ozalp M. and Kany´t E. G., 2004, Use of artificial neural networks for mapping the solar potential in Turkey, Appl. Energy 77: 273–86.

Spencer, J. W., 1975, Fourier series Representation of the Position of the Sun, Search, Vol. **2** No. 5, 165–172.

Steven M. D. and Unsworth M. H., 1980, The angular distribution and interception of diffuse solar radiation below overcast skies, Quart J Roy Meteorol Soc.106: 57–61.

Supit I. and Van R., 1998, A simple method to estimate global radiation, Solar Energy 63:147–60.

Tamer K., Azah M. and Sopian K., 2012, A review of solar energy modeling techniques, Renewable and Sustainable Energy Reviews, 16; 2864-2869.

Temps R. C., and Coulson K. L., 1977, Solar radiation incident upon slops of different orientations, 19, 179 – 84.

Tian Y. Q, Davies-Colley R. J., Gong P. and Thorrold B.W., 2001, Estimating solar radiation on slopes of arbitrary aspect, Agric. Forest Meteorol., 109: 67–77.

Trabea A. A. and Shaltout M., 2000., Correlation of global solar radiation with meteorological parameters over Egypt, Renewable Energy 21: 297-308.

Trabea A. 2000, Analysis of solar radiation measurements at Al-Arish area, North Sinai, Egypt. Renew Energy 20: 109–25.

WMO 1990, Guide to Meteorological Observations Methods, Tn-8, Geneva, Switzerland, Chapter 9, WMO Secretariat, pp. 925– 932. 238.

WRC 1985: Sixth international pyreheliometer comparison, (IPC VI), 1– 18 October, Working Report No., 137, Davos, Switzerland.

WRC 1995: International pyreheliometer comparison (IPC VII), 25 September-13 October, Working Report No.188, Davos, Switzerland.

Yohanna J., Itodo I. and Umogbai V., 2011, A model for determining the global solar radiation for Makurdi, Nigeria. Renew Energy 36:1989–92.

Zarzalejo L., Ramirez L. and Polo J., 2005, Artificial intelligence techniques applied to hourly global irradiance estimation from satellite-derived cloud index. Energy 30: 1685–97.